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Abstract: Chinese government commits to reach its peak carbon emissions before 2030, which requires China to implement new policies. Using a CGE model, this study conducts simulation studies on the functions of an energy tax and a carbon tax and analyzes their effects on macro-economic indices. The Chinese economy is affected at an acceptable level by the two taxes. GDP will lose less than 0.8% with a carbon tax of 100, 50, or 10 RMB/ton CO2 or 5% of the delivery price of an energy tax. Thus, the loss of real disposable personal income is smaller. Compared with implementing a single tax, a combined carbon and energy tax induces more emission reductions with relatively smaller economic costs. With these taxes, the domestic competitiveness of energy intensive industries is improved. Additionally, we found that the sooner such taxes are launched, the smaller the economic costs and the more significant the achieved emission reductions.

Keywords: Energy tax, Carbon tax, Climate change, CGE model, Energy intensive industry
JEL classification: C13, C15, C54, E37, J21, K32, O44, Q54

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Lele ZOU[1], Jinjun XUE[2], Alan FOX[3], Bo MENG[4], Tsubasa SHIBATA[4]

Abstract:

Chinese leader Xi Jinping announced during a meeting with President Barack Obama at the Peking APEC Summit that China will be expected to reach its peak carbon emissions before 2030. This is the first time the Chinese government stated a hard target (not a soft target such as intensity reduction) for reducing CO2 emissions. To meet the target, China intends to undertake more serious measures and implement new policies to limit the total volume of emissions. The new policies under discussion include a carbon tax, an energy tax, an emissions trading scheme (ETS), and cap-and-trade systems. Using a CGE model, this study conducts simulation studies on the functions of an energy tax and a carbon tax and analyzes their effects on economic growth and employment in China as well as their impacts on the energy intensive sectors in different scenarios. We found that the Chinese economy is affected at an acceptable level by the two taxes. GDP will lose less than 0.8% with a carbon tax of 100, 50, or 10 RMB/ton CO2 or 5% of the delivery price of an energy tax. Thus, the loss of real disposable personal income is smaller. Compared with implementing a single tax, a combined carbon and energy tax induces more emission reductions with relatively smaller economic costs. With these taxes, the import and export of energy intensive industries are changed, leading to improved domestic competitiveness. We further show that for China, the sooner such taxes are launched, the smaller the economic costs and the more significant the achieved emission reductions.

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1. Introduction

The Chinese government made a commitment at the COP19 in 2009 to reduce CO2 intensity by 40–45% from 2005 levels by 2020. The commitment was incorporated into its 12th Five-year Plan (State Coucil 2012) issued in 2011, through the dual reduction targets of 16% for CO2 and 17% for energy intensity by 2015. Nonetheless, China's total volume of CO2 emissions has been rapidly increasing. To meet this international commitment and reach a concrete accomplishment of the planned targets, the Chinese leader, Xi Jinping, made an announcement during a meeting with President Barack Obama that China will likely reach its carbon emissions peak before 2030. This is an important signal showing that China will take more serious measures to control total emissions.

However, China is currently facing serious challenges of slowing economic growth and inefficient energy use. To form a concrete plan and shape an efficient policy, China needs to carry out more research on how to achieve the targets, what will be the most efficient policy, and what sort of technology should be used.

Many policy instruments have already been implemented; however, most of them are not efficient. To foster new thinking about policies under Xi's administration, in recent years a number of different economic instruments have been widely discussed. Carbon and energy taxes, an emissions trading scheme (ETS), and a cap-and-trade system are some examples. Using a CGE modeling approach, this study focuses on environmental and carbon taxes policies by analyzing their effectiveness in reducing carbon emissions while maintaining economic growth and employment in China.

The study is organized as follows. Section 2 provides a literature review; section 3 explains the contents of the environment and carbon taxes. Section 4 compares the different impacts of the two taxes on the Chinese economy; and section 5 presents a brief conclusion.

2. Research review

China has no specific separated tax category for energy, rather a value added tax for energy selling, a consumption tax for energy use, and a resource tax for energy exploration (see Appendix 1). In this study, the term "energy tax" refers to the tax levied on energy sources as commodities and is thus close to the existing "resources tax."

Resources taxes were first implemented in 1994, which covered seven categories of resources: crude oil, natural gas, raw coal, ferrous metals ore, nonferrous metals ore, other non-metal ores, and salts. These taxes were based on the amount. For example, the taxes for crude oil, raw coal, and natural gas were 14–30 RMB/ton, 0.3–2.4 RMB/ton, and 7–15 RMB/thousand cubic meters, respectively. Because of the fixed low taxation rates and the amount based collection, which accounted for only 0.61% in the total national taxation income (Ifeng 2010), resources taxes were unable to reflect the environmental costs and price fluctuations. In 2009, the fuel tax was launched, which was expected to be more effective in adjusting the use of resources. Since 2010, resource taxes gradually changed into price-based ones, first in China's western regions, followed by the eastern regions; the tax rates for crude oil and natural gas have been set at 5% of the delivery price. However, due to the large proportion of coal in the energy structure—70% share of total energy use and about 80% of power generation—it was not included in the tax. In many other countries, an energy tax has been applied for decades, which is called fuel tax in most cases. Of these taxes, the most basic categories are an ad valorem duty and a specific duty. Because of the different yields and costs of different kinds of fuels, fuel taxes are becoming increasingly detailed in practice. In 2014, the proposed fuel tax under debate in the European Union (EU) focuses on returning to carbon and energy composition-based taxing with an additional floor rate to debate emissions from diesel, whereas the current one is based on amount of consumed fuels.

Numerous researches have been conducted on fuel tax-related issues from various aspects. For example, regarding the mechanism of the economy and politics (Hammar, Löfgren et al. 2004; Sterner 2007), the relationship with other taxes or fees (Parry and Small 2005; Zhou, Levine et al. 2010), their effectiveness in saving energy and reducing emissions (Bartocci and Pisani 2013; Mazumder 2014), and their impacts on national- or household-scale economies (Sterner 2012; Haufler and Mardan 2014; Jiang and Shao 2014), etc.

Fossil fuel conservation is not the only issue of concern to China. Greenhouse gas emissions control is another huge and urgent challenge. A carbon tax has been under consideration for several years now in China. Some argue that a carbon tax is more effective than an energy tax in reducing CO2 emissions while simultaneously reducing energy consumption. For example, Li (2003) uses an econometric model to analyze China's energy use under a carbon tax of 36.70 CNY/ton CO2 and concluded that in 2030, such a tax would reduce China's CO2 emissions by 9.3% while reducing primary energy consumption by 7.3% compared with 2010 (Li 2003). Jiang et al. (2009) conducts a similar analysis, but extends the time scale to 2050 (Jiang, Hu et al. 2009). However, this study contains no implementation of a pure carbon tax; some researchers prefer to treat it as a resource tax because a carbon tax most closely relates to emissions, while others argue that it should be categorized as a specific tax because it is based on the quantity of carbon embodied in the fuel.

Much research has focused on carbon taxes. Some scholars compare the effectiveness of CO2 emission controls (Lin and Li 2011; Cosmo and Hyland 2013); some compare carbon taxes with other policy instruments (Gerlagh and Zwaan 2006) and their impacts on both the macro and micro economy (Conefrey, Gerald et al. 2012). In many studies, a carbon tax is analyzed together with a cap-and-trade system because of the carbon restriction inherent in both mechanisms (Johnson 2007; Fischer and Springborn 2011; MacKenzie and Ohndorf 2012; Jenkins 2014). Because of their focus on carbon, the energy- or emission-intensive sectors or enterprises have received greater attention, especially in China (Liang, Fan et al. 2007; Xin Wang 2011; Fang, Tian et al. 2013; Martin, Preux et al. 2014).

In general, both taxes have been found effective to different extents for energy conservation and emissions reduction. The application of these systems in some countries has already shown the cost-effectiveness in CO_2 emission reductions of mixed taxes (Lin and Li 2011; Cosmo and Hyland 2013). In the research of Cosmo and Hyland (2013), they note that the implementation of a carbon tax should be considered carefully in terms of the interaction with existing energy taxes, and vice-versa. A practical example is the case of Sweden, where the fuel tax applies to oil, coal, and natural gas. When the emission tax on CO_2 was launched in 1991, the overall energy tax burden level was reduced.

The mechanisms of these two taxes are different: a carbon tax reduces CO_2 emissions through fuel selection by carbon pricing and works directly on emissions, whereas an energy tax works broadly on influencing fuel prices, encouraging conservation, but has a smaller effect on stimulating fuel switching than on total amount of energy use. Indeed, a carbon tax equalizes the marginal cost of CO_2 abatement across fuels, and therefore satisfies the condition for minimizing the global cost of reducing CO_2 emissions (Zhang and Baranzini 2004). A carbon tax levied on fossil fuels based on their carbon contents gives clear price signals on carbon cost and covers most CO_2 emission sources (Baumol and Oates 1998).

Because of the relationship and difference between the energy and carbon tax, the long- and medium-term effects of the two taxes differ. However, no definitive analysis has yet been conducted regarding how different they are or on their differential effects on various sectors of the economy. Given that China is a developing country and Chinese policy favors economic development, any politically feasible carbon or fuel taxes must balance economic development and its effect on carbon emissions. In this study, we aim to analyze the impacts of two economic instruments, a carbon tax vs. an energy tax, especially their impacts on heavy industries, which are regarded as the backbone of China's economy.

3. Analytical Approach

3.1 Assumptions

There are several ways to levy energy and carbon taxes. In some countries, the coordination of carbon and fuel taxes varies. For example, in the Netherlands the carbon tax was launched without simultaneously changing the country's original tax structure. However, in Finland, Sweden, and Denmark the existing energy tax was reduced when the carbon tax was introduced. In contrast, in Norway the energy tax was increased when the carbon tax was introduced. In China, the existing resources tax and the structure of other taxes imply energy and carbon taxes most similar to those in the Norwegian system.

In this study, we assume a carbon tax will be based on CO_2 emissions[1]. Given the current price controls on fuels in China and to simplify the analysis, we assume that the carbon tax will

[1] Considering the method of calculating CO_2 emissions by combining the IO table and energy balance, the emissions here are not specifically from combustion or industrial process, but overall totals.

increase the market price of all fossil fuels, and the incremental costs will be fully passed on to downstream industries as direct impacts. This assumption is reasonable because the controlled prices are not completely rigid but adjusted by government authority based on certain rules (see Table 1). The model implementation of the energy tax follows the same assumptions.

Table 1: A Description of the Energy Pricing System in China

Energy type	Pricing	Adjustment bases
Refined oil products	Government guided price	When the moving average price of the international market crude oil for 22 continuous working days changes more than 4%, the domestic price is adjusted based on both processing margins and international crude oil prices.
Natural gas	government guidance price	Based on the 5-year average price of crude oil, LPG and coal, by weights of 40%, 20% and 40%, respectively. The change should not exceed 8% in two adjacent years.
Electricity	Government guidance price	Pricing on regular period：the delivered price is checked annually; if little change between annual costs, the sales price remains unchanged；Linkage pricing: linked with grid power price and is only for industrial and commercial. The adjustment interval should be more than one month.
Crude oil	Market-set price	Based on the changes of supply and demand
Coal	Market-set price	Based on the changes of supply and demand.

(Data source: collected and cleared up based on National Development and Reform Commission (NDRC) documents[2])

The original goal of a carbon or energy tax is to promote energy switching and conservation, and therefore the elasticity of energy substitution and demand are important. Substantial differences exist among countries in terms of fuel taxation that, in turn, can lead to large differences in final consumer price (Sterner 2012). As China controls energy prices, its demand price elasticity does not fit the short-term supply and demand relation very well. However, it remains reasonable to assume in long-term that the elasticity can reflect the fuel energy market due to the governmental price control regime. Therefore, following the literature (Johansson and Schipper 1997; Ngan 2010; Xin Wang 2011; Sterner 2012), the overall fuel price elasticity is set as −0.7. As more than 90% of the electricity is generated from fossil fuels [in 2012, the proportion of fossil electricity was 90.2% (NBSNA 2013)], the substitution elasticity between electricity and fossil fuels is higher compared with the substitution elasticity among different fossil fuels.

To make the analysis simple and direct, in this simulation we assume in all scenarios that no significant technical progress occurs in energy use or CO2 emission reduction. Furthermore, no dramatic change occurs in the energy structure, following the targets of the 12th Five-year Plan.

2 In this study, all the figures and tables without notes on data sources are calculated by the authors.

3.2 Models

Substantial challenges exist regarding acquiring energy data in China. For example, sectoral fossil fuels consumption values are not directly available in the Statistical Yearbook of China. In addition, among the 30 categories of energy in the Annual Energy Balance, only seven sectors concern “Input & Output of Transformation” and seven sectors address “Final Consumption.” While the I-O Table has 58 sectors, there are only a few main energy types. Therefore, to obtain emissions data, we have to calculate energy consumption and CO2 emissions in each sector by combining the two tables.

The method we used to calculate energy use and CO2 emissions is as follows:

Total energy use = Total Final Consumption + Transformation in Power Generation and Heating

Total CO2 emissions of a certain type of energy = CO2 emission factor[3] of the energy * amount of energy use

CO2 emission coefficient of a certain type of energy = Total CO2 emissions of the certain type of energy/(Total intermediate use + Total final use − diagonal value of energy sectors)

CO2 emissions of a certain type of energy in a certain sector = CO2 emission coefficient of the certain energy * (Total intermediate use − diagonal value of energy sectors)

Although using the above method we can only calculate each sector’s energy use for 2007, it is reasonable to assume that without dramatic changes in energy structure or energy technology, the energy portfolio of each sector remains approximately the same in subsequent years. In this study, 14 energy types are included in the analysis and their energy uses in different sectors are shown in Appendix 2.

By the above assumptions and data process, we implement a multi-regional general equilibrium model based on the 58 sectors of the 2007 Chinese National IO Tables and combined with economic geography to capture trade between 32 regions (provinces) in China. The original version of this model has been employed in US government agencies to evaluate impacts of various policies (Miller, Wei et al. 2010; Rose, Wei et al. 2011). In this implementation, the production module specifies the production activity in each sector. The production function is Cobb–Douglas, and the inputs in each sector include labor, capital, energy, and other intermediate inputs, following a five-level nested constant elasticity of substitution (CES) function as shown in Figure 1. As energy consumption is sensitive in some sense to capital investment in China, reducing energy consumption is closely related to capital investment types. Therefore, in this model, the energy

[3] The CO2 emission factors are from 2006 IPCC Guidelines for National Greenhouse Gas Inventories http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_x_An1_Worksheets.pdf

input changes together with capital inputs, which accompanies substitution for labor. The substitution elasticity in this model is drawn from Ma, Oxley et al. 2009.

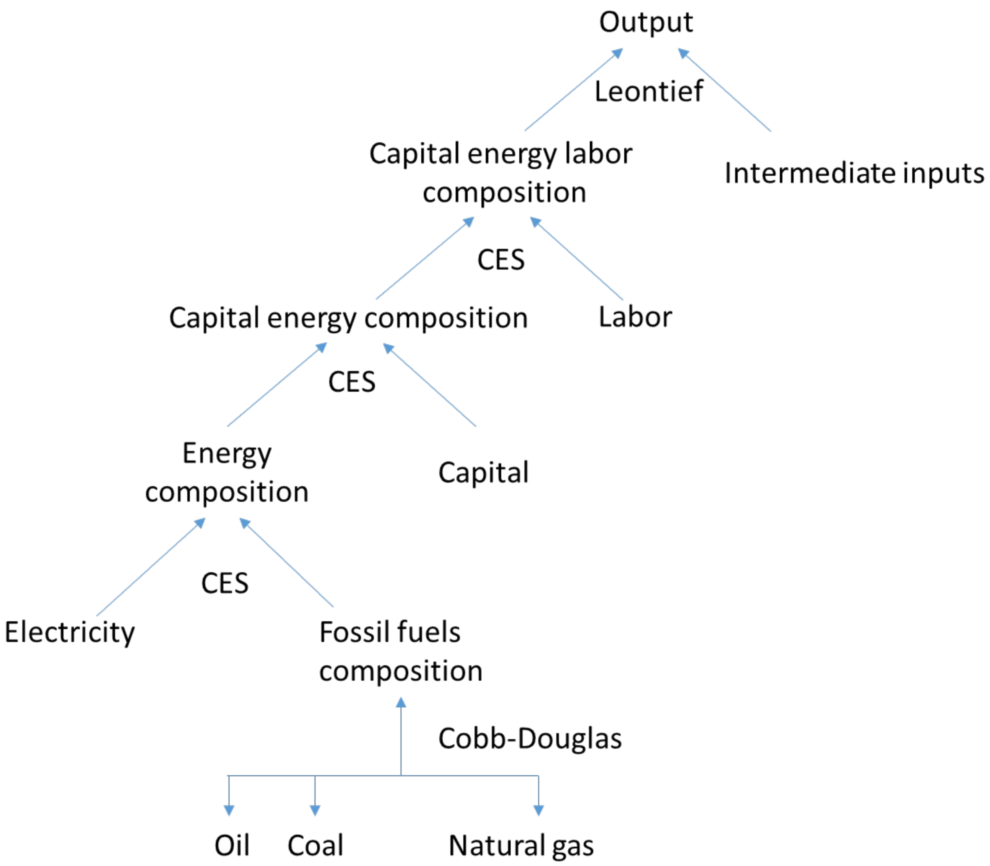


Figure1 Nested production function

For imports, the cost insurance and freight (CIF) value of imported goods is based on the world market price of imported goods plus customs duties and transport costs. Local and imported goods are aggregated through CES functions. Therefore, demand for domestic and imported goods from a given region will be calculated based on the CES function, which minimizes costs. This composite good is used as either intermediate input or final use together with inflow from other regions.

Total exports are calculated using a CES function based on the free on board (FOB) prices and imperfect substitution. World demand for Chinese exports is an exponential function of relative prices. This function has a positive elasticity parameter; this means that when the domestic price of an export good rises, global demand of this certain good will decrease. The import and export structure of the model is shown in Figure 2.

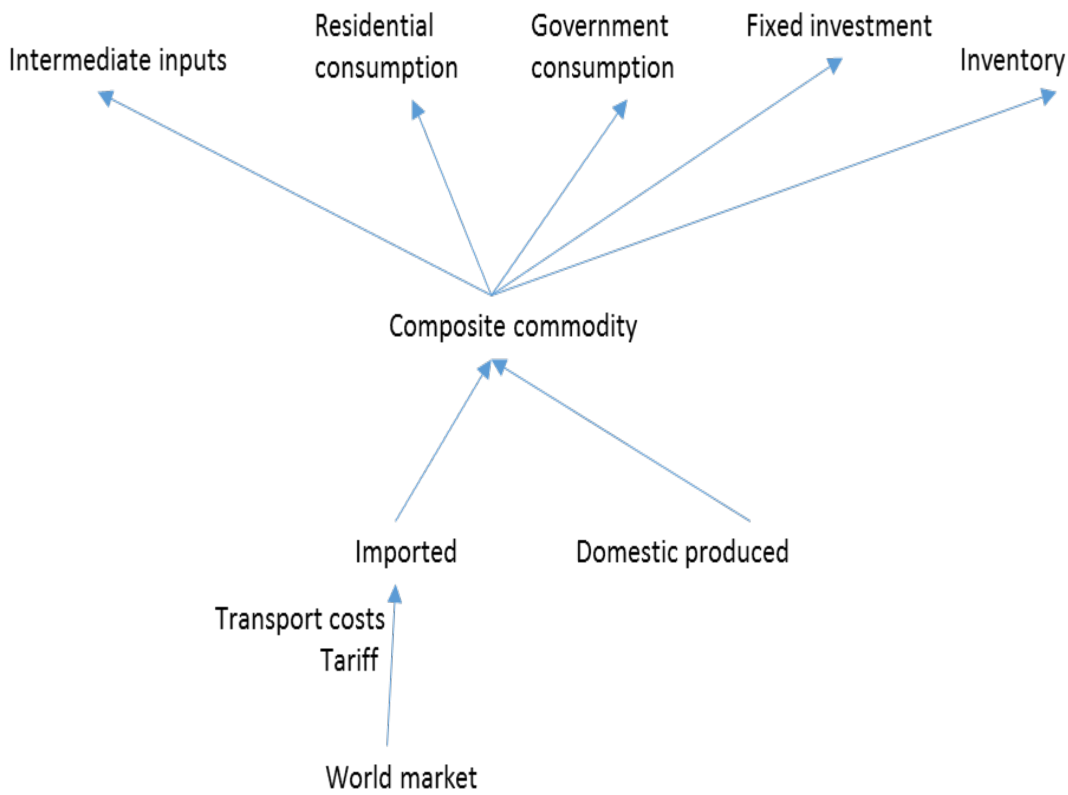


Figure 2 Import and Export Structure

In this study, the marginal rise in costs brought about by taxes is directly reflected in the increase in factor prices, which introduces the tax rate variable into the model. Then in a complete market, for a given output, producers decide the combination of inputs based on minimum costs. The production activity is presented as below:

$$\text{Min.} \sum_{i=1}^{m} P_i(1+t)X_{ij} \quad (1)$$

$$\text{s.t.} \quad X_j = A_j \sum_{i=1}^{m} X_{ij}^{\alpha_{ij}}, \text{ where} \sum \alpha_{ij} = 1 \quad (2)$$

The Lagrange equation (3) is then differentiated. The demands of sector j for labor, capital, and energy are then determined. In equation (1), $P_i(1+t)$ could be taken as an integrated variable.

$$\text{L} = \sum P_i(1+t)X_{ij} + \lambda[X_j - A_j \sum P_i X_{ij}^{\alpha^{ij}}] \quad (3)$$

$$X_{ij} = [\alpha_{ij} \prod (\frac{\alpha_{ij}}{A_j}) X_j \prod P_i^{\alpha_{ij}} \frac{1+t}{P_i(1+t)}] \quad (4)$$

where X_{ij} is the demand of sector j on factor i; P_i is the corresponding factor price; $\sum_{i=1}^{m} P_i(1+t)X_{ij}$ is the total cost of sector j; α_{ij} is the direct consumption coefficient; X_j is the total output of sector j; and t is the tax rate.

Similarly, the consumption activity function maximizes utility by combining commodities under the budget constraint, as shown in equations (5) and (6):

$$\max \prod_{i=1}^{n} X_{ic}^{\alpha_{jc}}, \text{ where} \sum_{i}^{n} \alpha_{ic} = 1 \qquad (5)$$

$$\text{s.t.} \quad \mathrm{M} = \sum_{i=1}^{n} P_i(1+t)X_{ic} \qquad (6)$$

where X_{ic} is the consumer demand for commodity i; α_{ic} is the slope coefficient; and M is the total budget of consumers. Further, the Lagrange equation is expressed as (7):

$$\mathrm{L} = \prod_{i=1}^{n} X_{ic}^{\alpha_{jc}} + \lambda[M - \sum_{i=1}^{n} P_i(1+t)X_{ic}] \qquad (7)$$

After differentiation, the consumer demand of commodity i is as follows:

$$X_{ic} = \alpha_i \frac{M}{P_i(1+t)} \qquad (8)$$

3.3 Data sources and processing

In the standard Chinese IO tables, there are 42 sectors in the various industrial categories. To help analyze the impact of fuel and carbon taxes on different fuels, the standard IO table of 2007[4] is expanded into 58 sectors by splitting the energy-producing sectors of Mining and Washing of Coal; Petroleum and Natural Gas Extraction; Petroleum Processing, Coking, and Nuclear Fuel Processing; and Electricity and Heat Production and Supply by relying on the 135-sector IO table (as shown in Appendix 3).

As Chinese IO tables are based on a competitive imports assumption that treats imported products the same as domestic varieties, it is necessary to separate emissions embodied in imported and exported goods. Some studies are working on analyzing the emissions embodied in international trade using different methods. A comprehensive one is the study conducted by Koopman et al. (2014). In that study the authors developed a method to extract the value-added from Chinese exports by distinguishing between processing and normal trade. However, because of

[4] Because the 2010 national IO table is the expanded table based on 2007 IO and there is no 135-sector IO for 2010, in this study we use the 2007 national IO table.

the complexity required to implement the method in Koopman et al. (2014), this study treats the rest of world as one region, and imported and exported goods are assumed to be of the same quality.

The CO2 emission factors of fuels are calculated based on the intergovernmental panel on climate change (IPCC) guidelines for national greenhouse gas inventories, with conversion to weight-based unit as shown in Table 2.

Table 2 Emission factors of Various Fuels

Emission factor	**Unit**	**Fuel type**
2.0483	Ton of CO2/ton energy use	Coal
2.5808	Ton of CO2/ton	Cleaned Coal
0.8193	Ton of CO2/ton	Other Cleaned Coal
3.0651	Ton of CO2/ton	Crude Oil
21.8403	Ton of CO2/10,000 cubic meters	Natural Gas
3.0149	Ton of CO2/ton	Gasoline
3.0967	Ton of CO2/ton	Kerosene
3.1605	Ton of CO2/ton	Diesel Oil
3.2366	Ton of CO2/ton	Fuel Oil
3.1663	Ton of CO2/ton	LPG
3.0651	Ton of CO2/ton	Other Petroleum Products
3.0425	Ton of CO2/ton	Coke
7.4263	Ton of CO2/10,000 cubic meters	Coke Oven Gas
3.2617	Ton of CO2/ton	Other Coking Products

3.4 Scenarios Setting

Energy and carbon tax rates are assumed in the following scenarios. According to some previous studies, China’s carbon tax is expected to be uniform and relatively low to protect competitiveness and economic development (Wang, Yan et al. 2009; Lu, Tong et al. 2010). In this study, we set varied carbon tax in three scenarios: 100, 50, and 10 RMB/ton of CO2 in scenarios A1, A2, and A3, respectively. Energy and carbon tax rates are set based on the consideration that they have comparable effects on the cost increase, which indicates that carbon and energy taxes will take a similar tax payment per unit of fossil fuel, which corresponds to scenario A3 and B. Scenarios C1, C2, and C3 are a compound of carbon and energy taxes.

Additionally, tax revenue recycling has also been discussed in the literature. To enhance the expected effects of tax instruments on emission reduction as well as to mitigate the unevenness of income reallocation (Chamon, Liu et al. 2013; Du, Liu et al. 2014), revenue is recycled by reducing indirect taxes and giving a price subsidy to households.

Noting that most current energy tax proposals only focus on adding a tax on the primary energy (Han, Su et al. 2008; Liu and Sun 2014), we set the scenarios of energy tax as “only implemented on primary energy of oil, coal, and natural gas” to more closely approximate reality and avoid distraction.

Table 3 Simulation Scenarios

Scenario	**Description**
A1	Carbon tax: 100 RMB emission
A2	Carbon tax: 50 RMB/ per ton CO2 emission
A3	Carbon tax: 10 RMB/ per ton CO2 emission
B	Fuel tax: 5% of the delivered price for oil, coal, natural gas
C1	A1+B
C2	A2+B
C3	A3+B

4. Simulation Results

4.1 General Economic Impacts

In all five scenarios, we simulate the impacts of different tax combinations on Chinese macroeconomic indicators and industrial structure. These taxes have the greatest effect on production costs and the prices of certain products and commodities. Table 4 shows changes in GDP, real disposable personal income, and the price index.

The results indicate that imposing a carbon or energy tax will have negative impacts on all indicators. But the magnitudes of the impacts differ. Basically, as described in equations (1)–(8), the energy tax will first shock the delivered prices of crude oil, raw coal, and natural gas; further, the impacts are passed downstream through production costs of all commodities before finally affecting household consumption. In contrast, the carbon tax is levied directly on emitters, covering all manufacturing industries and imposing costs according to their emission intensities. Because of the different functioning of the two mechanisms, from Table 4 it can be observed that the effect on GDP in carbon tax-only scenarios (A1–A3) is larger than those observed in fuel tax scenario (C1–C3). In contrast, real disposable personal income in scenarios C1–C3 is more adversely affected than in scenarios A1–A3.

Additionally, both the carbon and energy are somehow “shrinking taxes,” whose total revenues are shrinking along with reductions in total emissions or fossil energy use. In carbon energy taxes issues, along with the efforts of reducing total CO2 emissions or the amount of fossil energy use, the proportion of taxes out of production costs is shrinking. In Table 4, the negative impacts on GDP and real disposable income both diminish over time despite fluctuations in the beginning phase.

By comparing scenarios A1–A3 with C1–C3, we find that the impacts of the combined carbon-energy tax mix are not equal to the effects of a single carbon tax and a single energy tax. In year 2015, the impacts of A1 and C1 on GDP are both −0.381%. Additionally, in most of the time points (2020–2040) the impacts of C1 (A1 + B) on GDP are quite similar to those of A1. However, in the final years (2035–2040) the impacts of C1 become smaller than those in A1. This could reflect the fact that both the carbon and fuel taxes work on fossil energy consumption and related emissions, so that when these two taxes are implemented simultaneously, the subject of the carbon tax is no longer producing the same emission amounts as without the fuel tax, and vice versa. In other words, these two taxes "weaken" each other. In terms of real disposable personal income, the effects in the A scenarios are bigger than those in the C scenarios, as shown in Table 4. Because the carbon tax impacts the general price (PCE-price index) less than energy tax, real disposable personal incomes in A scenarios are affected less than those in C scenarios.

Table 4 Impacts on GDP and Real Disposable Income

	2015	2020	2025	2030	2035	2040
GDP						
A1	-0.381%	-0.762%	-0.581%	-0.496%	-0.480%	-0.458%
A2	-0.194%	-0.392%	-0.293%	-0.250%	-0.243%	-0.232%
A3	-0.039%	-0.080%	-0.059%	-0.050%	-0.049%	-0.047%
B	-0.193%	-0.351%	-0.285%	-0.265%	-0.276%	-0.286%
C3	-0.039%	-0.080%	-0.059%	-0.050%	-0.049%	-0.047%
C2	-0.193%	-0.390%	-0.294%	-0.249%	-0.241%	-0.230%
C1	-0.381%	-0.758%	-0.582%	-0.496%	-0.476%	-0.454%
Real Disposable Personal Income						
A1	-0.391%	-0.658%	-0.514%	-0.458%	-0.467%	-0.464%
A2	-0.199%	-0.340%	-0.259%	-0.230%	-0.236%	-0.235%
A3	-0.040%	-0.070%	-0.052%	-0.046%	-0.048%	-0.047%
B	-0.271%	-0.378%	-0.319%	-0.302%	-0.317%	-0.331%
C3	-0.041%	-0.070%	-0.053%	-0.047%	-0.048%	-0.048%
C2	-0.202%	-0.343%	-0.264%	-0.234%	-0.237%	-0.235%
C1	-0.397%	-0.665%	-0.524%	-0.466%	-0.469%	-0.465%

Sectoral investment is affected directly in all scenarios, due to the rise in marginal production costs. Compared with consumption expenditure, the percentage decrease of investment is almost twice as much before 2025. Although lower after 2025, it remains more than 1.5 times the decline in consumption expenditure until 2040. An exception is scenario B, where the percentage drop in investment is between 1.2 to 1.9 times over consumption. This result indicates that the energy tax, as a broader based tax as mentioned above, affects not only manufacturing sectors, but also household consumption and commercial sectors through the price transmission of fuel products.

This is particularly true when considering that a relatively large proportion of petroleum products are used by residential vehicles and related transportation (see figures 3 and 4 below).

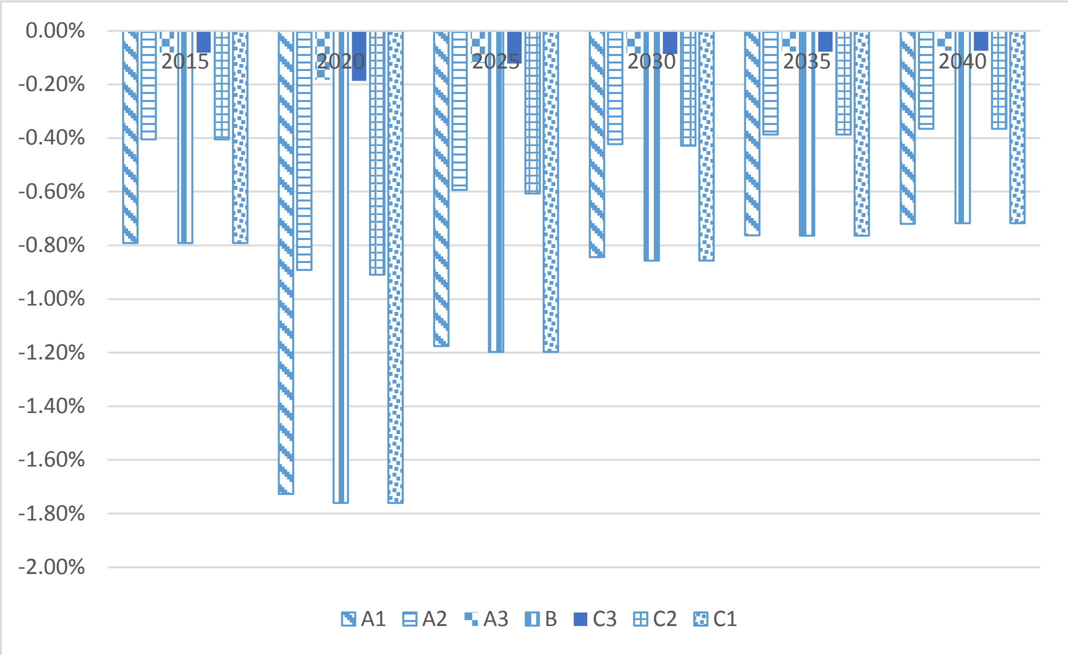


Figure 3 Change in Gross Private Domestic Fixed Investment

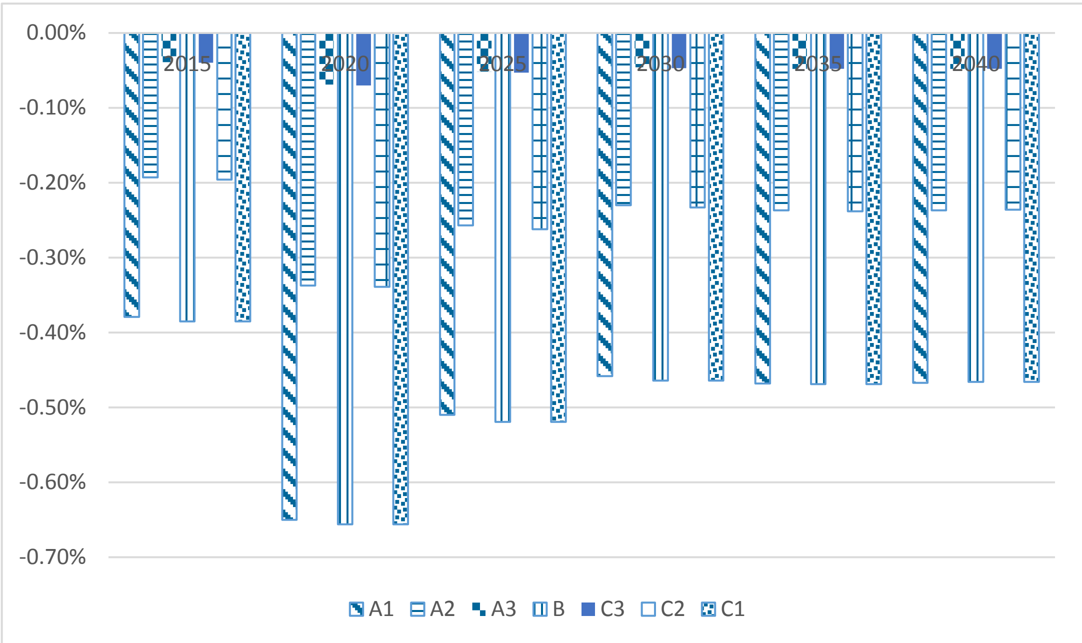


Figure 4 Change in Personal Consumption Expenditures

4.2 Impacts on CO2 emissions and energy use

Both the fuel and carbon taxes reduce CO2 emission and encourage energy conservation. Total amounts of energy use and CO2 emissions as well as their intensities both decrease.

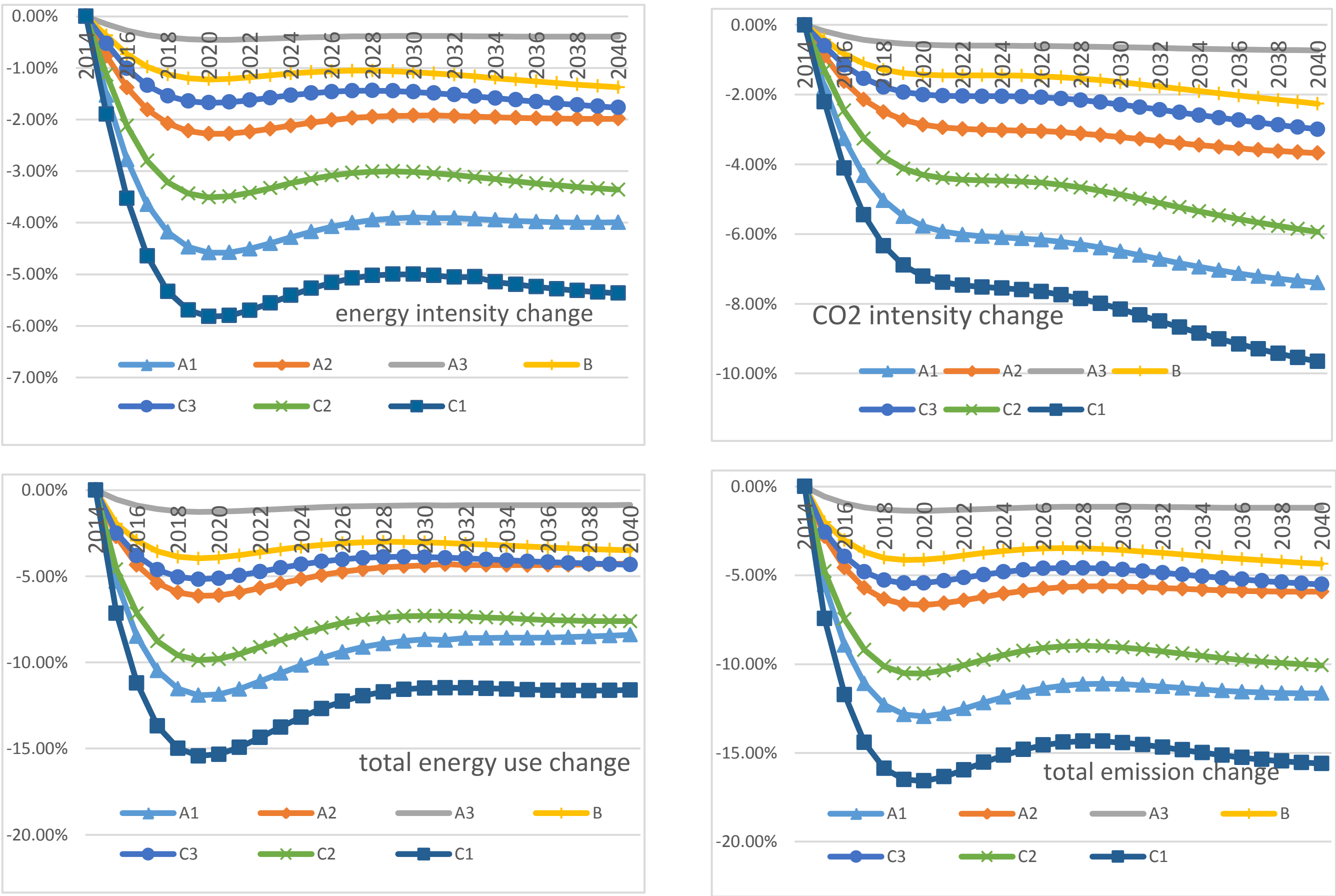


Figure 5 Changes in total energy use, energy intensity, total emissions, and emission intensity in all scenarios

Figure 5 shows that the total amounts of energy use and CO2 emissions as well as their intensities decrease. There appears to be a U-curve (some overshooting) in the changes of energy intensity, total energy use, and total emissions. Because we assume no dramatic change occurs in technologies, changes are determined by sectoral outputs. The changes can be characterized as occurring in three phases: 2014–2020 rapid decrease; 2020–2025 rebound; and 2025–2040 stable phase. In the rapid decrease phase, the effects of carbon and energy taxes are most significant. Although GDP is affected in this phase, energy consumption and related emissions decrease more quickly. The changes mainly stem from the effect of taxes on investment. In this model, total investment comprises three parts: residential, non-residential, and capital equipment. In addition, commercial inventory is also a part of investment, determined by current average price and based on the national change in inventories as a proportion of sales applied to the size of local industries (Richman, Shao et al. 1993). Residential and non-residential investment stocks are shown as below in Table 5.

Table 5 Changes in Regional Residential and Non-residential Capital Stock across Scenarios

Scenario	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
A1						
Residential Capital Stock	-0.036%	-0.402%	-0.540%	-0.509%	-0.483%	-0.477%
Nonresidential Capital Stock	-0.055%	-0.584%	-0.872%	-0.904%	-0.872%	-0.836%
A2						
Residential Capital Stock	-0.019%	-0.208%	-0.277%	-0.258%	-0.244%	-0.241%
Nonresidential Capital Stock	-0.028%	-0.301%	-0.447%	-0.460%	-0.442%	-0.424%
A3						
Residential Capital Stock	-0.004%	-0.043%	-0.056%	-0.052%	-0.049%	-0.049%
Nonresidential Capital Stock	-0.006%	-0.062%	-0.091%	-0.093%	-0.090%	-0.086%
B						
Residential Capital Stock	-0.021%	-0.190%	-0.249%	-0.241%	-0.238%	-0.244%
Nonresidential Capital Stock	-0.019%	-0.195%	-0.293%	-0.314%	-0.324%	-0.337%
C3						
Residential Capital Stock	-0.004%	-0.043%	-0.057%	-0.053%	-0.050%	-0.049%
Nonresidential Capital Stock	-0.006%	-0.061%	-0.091%	-0.094%	-0.090%	-0.086%
C2						
Residential Capital Stock	-0.018%	-0.208%	-0.279%	-0.262%	-0.247%	-0.242%
Nonresidential Capital Stock	-0.027%	-0.296%	-0.445%	-0.461%	-0.444%	-0.425%
C1						
Residential Capital Stock	-0.036%	-0.402%	-0.545%	-0.517%	-0.489%	-0.479%
Nonresidential Capital Stock	-0.053%	-0.573%	-0.868%	-0.907%	-0.875%	-0.838%

In fact, nonresidential capital stock is a more significant driving force for energy use reduction than residential capital stock. When the energy or carbon tax is first implemented, sectors would reduce new investments due to the rise in marginal production costs. Without adequate time to switch to new manufacturing technologies or energy alternative technology, new project investment mainly comprise relatively advanced technology. Over time, manufacturing sectors turn to energy-saving technology, low-carbon technology, or low-carbon energy; corresponding new investment gradually increases, which is relieved from the lock-in effects of the high-energy technology. When this new round of energy-saving investment is finished because of the relatively stable cycle of technology progress, no other more-advanced technology exists to replace it (notice that in this study, it is assumed that no dramatic change occurs in technology or energy). This slows the incremental accumulation of real capital stock.

4.3 Impacts on High Energy-Consuming Industries

According to a definition issued by National Development and Reform Commission (NDRC), the "high energy-consuming industries" are the non-metallic mineral products industry; chemical raw materials and chemical products industry; metal smelting and rolling processing industry; electricity and heat production and supply; and the petroleum processing, coking, and nuclear fuel processing industry (NBS 2011). These high energy-consuming industries are anticipated to be affected most by the carbon and energy taxes. In contrast, these industries are also the mainstay industries in China. In 2013, the value-added of these industries increased 10.1% on average since 2012, ranking fourth after automobile manufacturing (14.9%); computer, communications and other electronic equipment manufacturing (11.3%); and electrical machinery and equipment manufacturing (10.9%). Therefore, evaluating the impact of carbon and energy taxes on these industries is important. In general, the energy tax and carbon tax both effectively reduce energy use in these industries.

Figure 6 shows that the impact of the carbon and energy taxes differs by sector. Generally, employment in all sectors shrinks in the short run and recovers in the long run. In all carbon tax scenarios (A1–A3, C1–C3), the electricity and heat supply industry experiences the most modest employment impact while the policy is in effect. The non-metallic mineral products manufacturing industry bears the heaviest impact in 2020 (−14.86% and −15.09% in A1 and C1, respectively), but recovers after 2020 to be third most heavily affected sector with employment losses of 7.36% in both A1 and C1. In contrast, the effect of the carbon tax on the petroleum processing, coking, and nuclear fuel processing industry grows relatively larger in 2030 and 2040 compared with other industries, changing from the third largest in 2020 to the largest in 2040. In the scenario without a carbon tax (scenario B), the situation differs. Petroleum processing, coking, and nuclear fuel processing industries and the metal manufacturing and processing industry are the most affected in 2030 and 2040, and by 2030, the petroleum processing, coking, and nuclear fuel processing industry exceed the metal manufacturing and processing industry to become adversely affected. Another difference between the fuel and carbon taxes is that the impact in scenario B does not decrease along with time, unlike those in scenarios A and C. On the contrary, employment in 2040 in scenario B is lower than in 2030.

From the perspective of change extent, according to the impact on the whole economy, the fuel tax “offsets” the impacts of the carbon tax, which means the impact of C1 is very close to that of A1, but not to that of A1 + B. Figure 6 Impacts of carbon energy taxes on Employment in A1, B, and C1. Additionally, the output of these sectors follows same impacts from the carbon energy taxes, but the magnitude of change in output between industries is smaller than that seen for employment. Across all industries, Petroleum Processing, Coking, and Nuclear Fuel Processing see the greatest decline in output; almost all petroleum products such as diesel, gasoline, fuel oil, LPG, and others as well as coke products are included in this sector. In this broad industry, fuel oil is the most severely affected, bearing an output loss of 24.68% in 2020 and 26.73% in 2030, which is also the biggest loss across all industries. Nonmetallic Manufacturing and Processing bears a loss of 15.88% and 10.83% in these two years and ranks fourth out of all industries. Among the heavy industries, LPG displays the smallest amount of decrease in output in 2020, 7.06% less than the reference scenario, even less than professional and technical services industry, whose output declines by 7.29%.

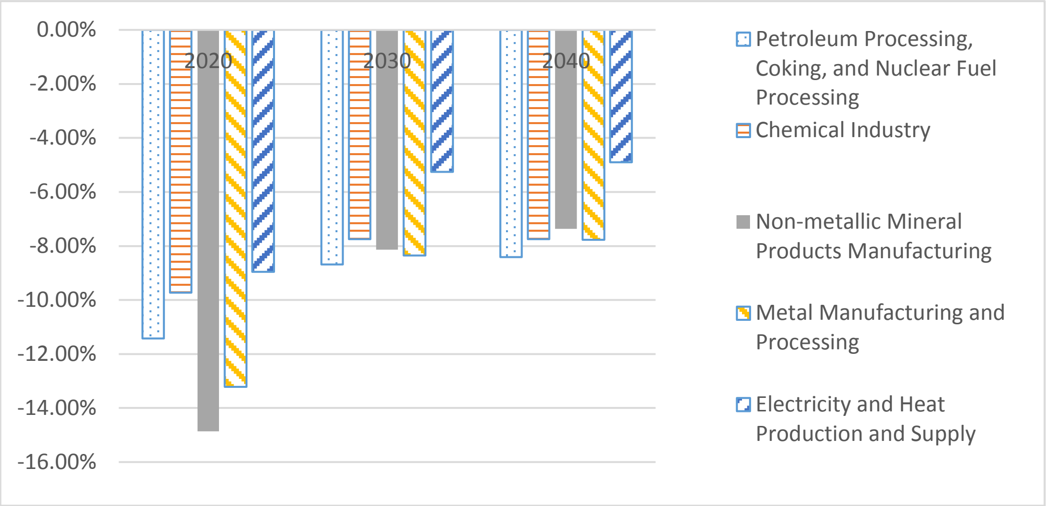


Figure 6-a Employment impacts of A1

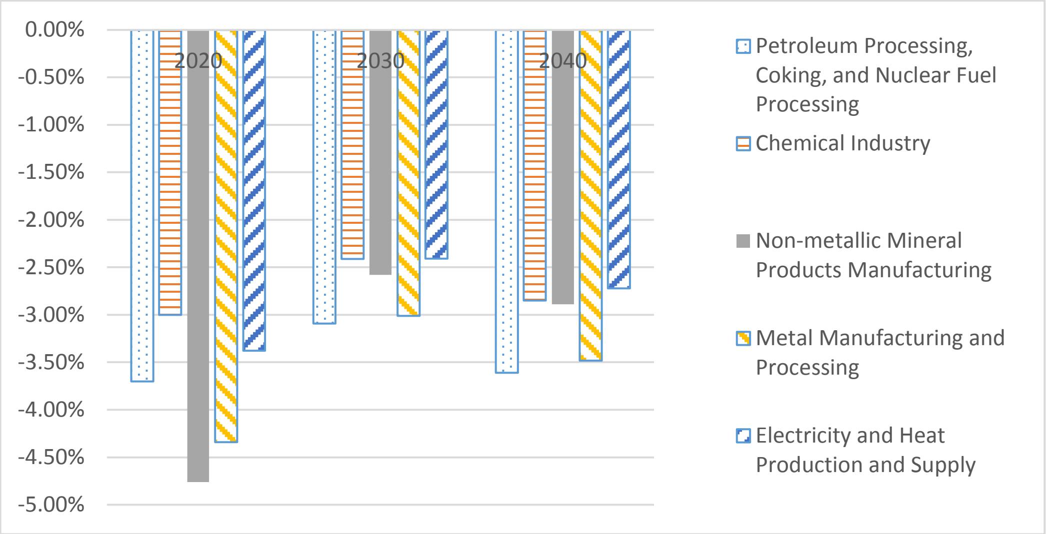


Figure 6-b Employment impacts of B

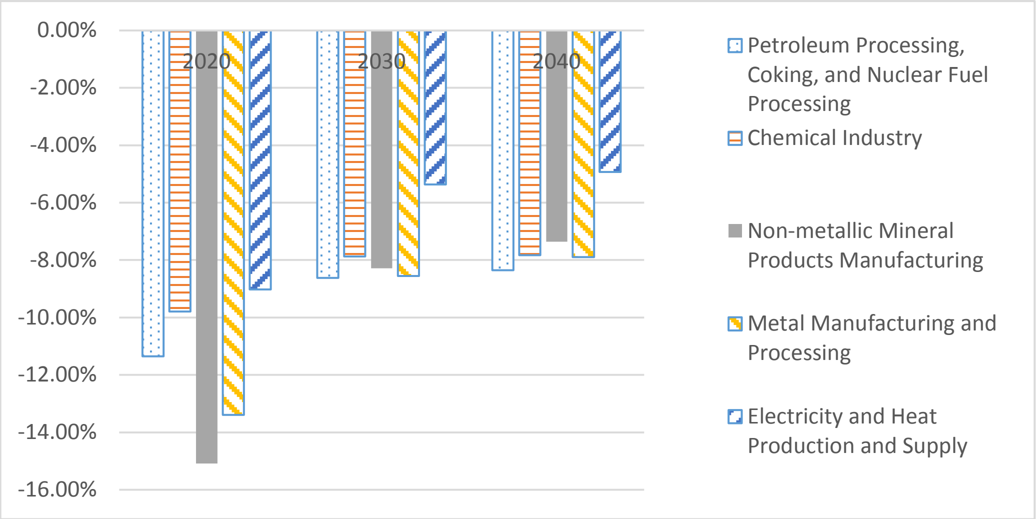


Figure 6-c Employment impacts of C1

The impact on energy use varies across different scenarios. Consistent with employment and output effects, the Nonmetallic Mineral Products Manufacturing sector experiences the greatest decline in energy use of any industry in 2020, falling by 20.12% (C1). The decrease of energy use in petroleum processing, coking, and nuclear fuel processing and metal manufacturing and processing industries rebound slower than other industries in the long term after 2020. Unlike with employment and output, the decrease in energy use involved in the carbon-energy combined tax is significantly greater than in carbon tax-only scenarios. In energy tax scenario (B), the energy use of the electricity and heat industry decreases more than the chemical industry; whereas, in carbon tax scenarios (As and Cs), the energy use of chemical industry decreases more than that of the electricity industry after 2020.

All these selected heavy industries contribute large energy savings to the whole economy. Their decreased proportions of energy use range from 32.3% to 94.5% compared with the baseline, which are much larger than the average reductions for all other sectors. Complete results are shown in Appendix 4.

4.4 Impacts of the Two Taxes on Imports and Exports of High-Energy-Consuming Industries

Carbon and energy taxes have different impacts on the total imports and exports as well as different sectors' imports and exports.

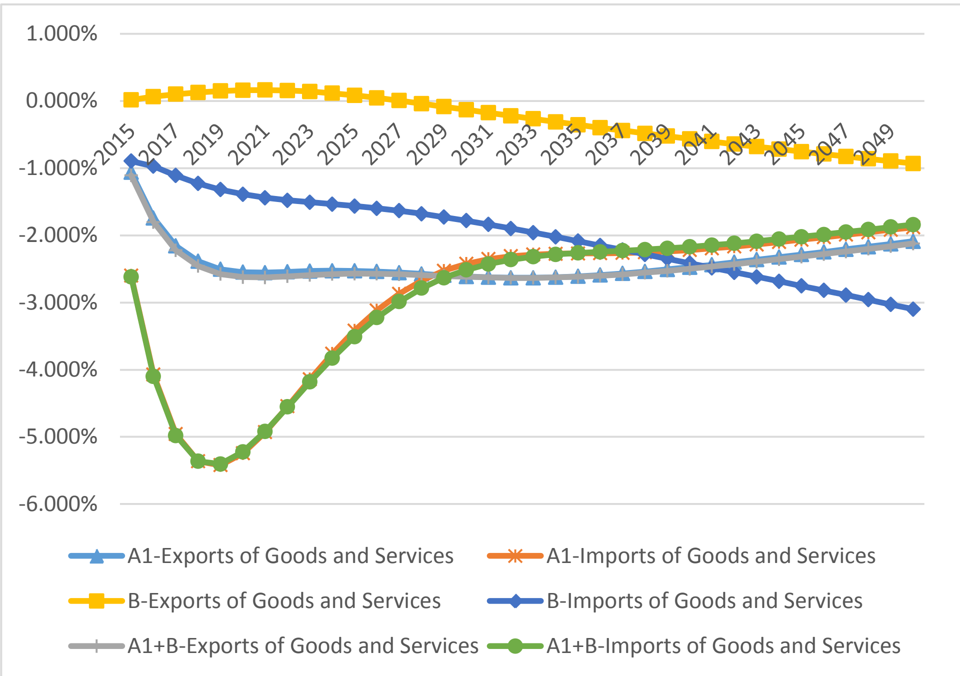
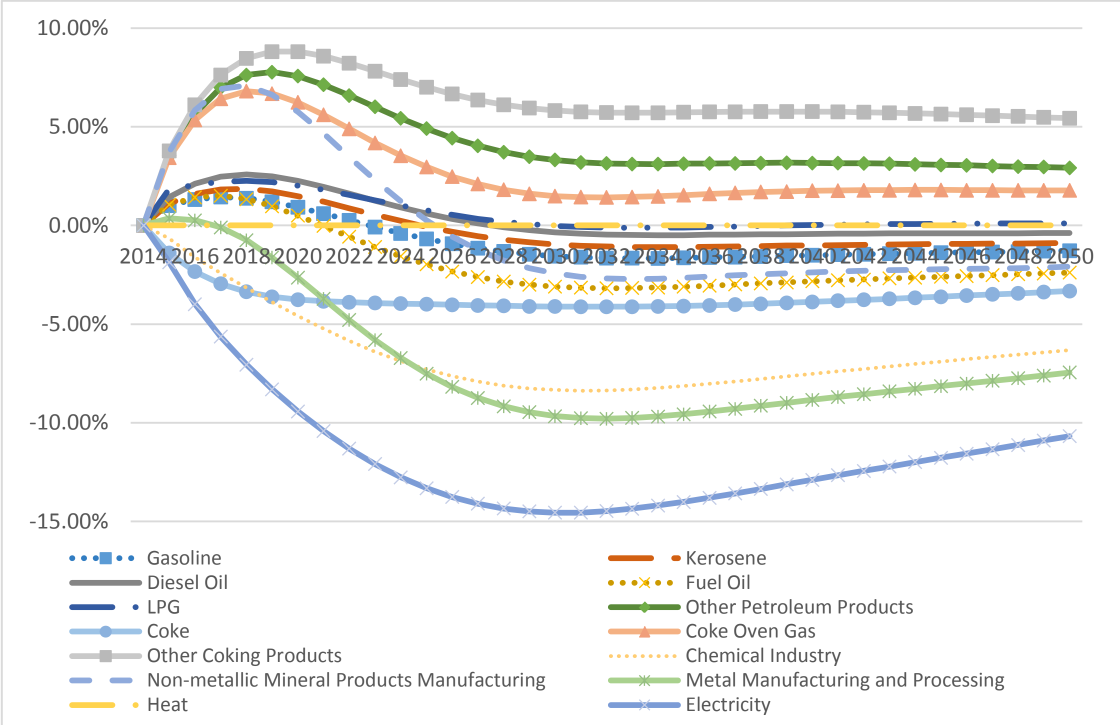


Figure 7 Export and import change in A1, B, C1 (A1+B) compared to baseline scenario

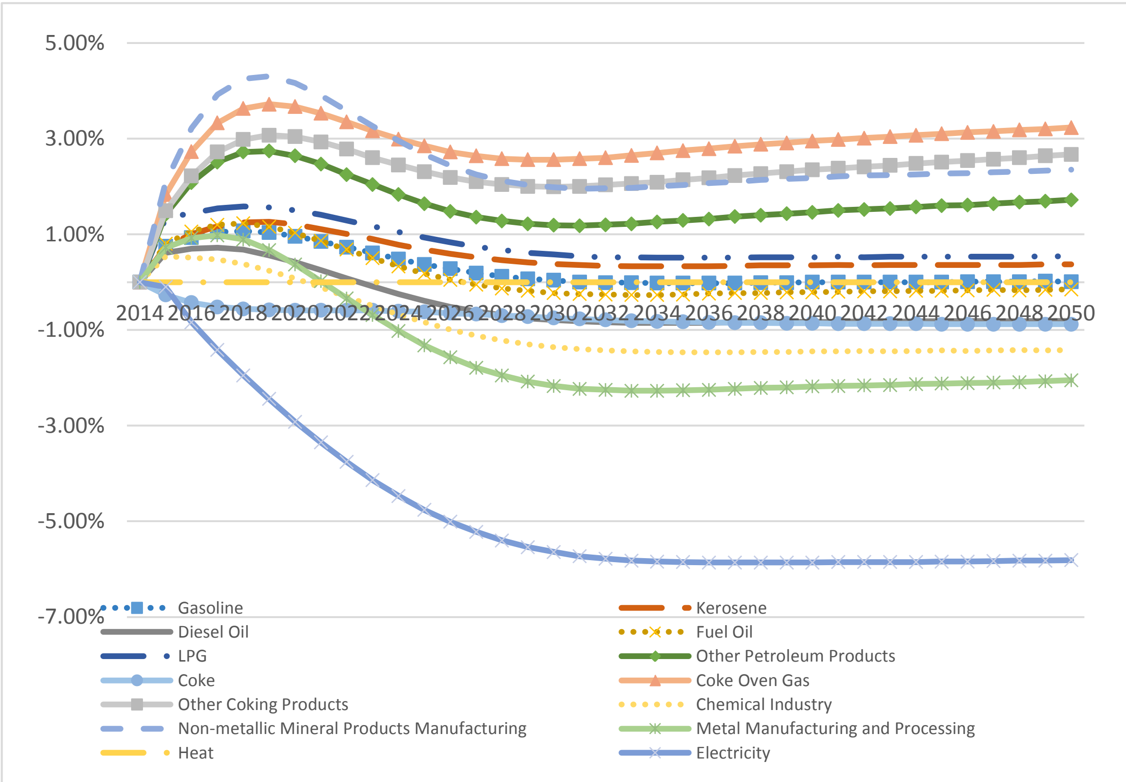
In these scenarios, the impacts of the energy and carbon taxes on exports are relatively steady with decreases of −2% to −3.5% relative to the baseline scenario (Figure 7-a)). However, their impacts on import are more significant. In scenarios with a carbon tax (A1 and A1 + B), after a short time of the tax being implemented, imports drop significantly, close to −6% in 2019, followed by a slower increase. However, the impact on imports from an energy tax only (B) is relatively much smaller. As the carbon tax targets all emissions, including those in sectors that do not consume much energy directly but still have CO2 emissions such as the chemical industry and transportation industry, the whole economy is affected by the increased costs facing most sectors. Therefore, production in all these sectors is affected, including those sectors that rely principally on imported intermediate inputs. In contrast, the energy tax is more focused on the sectors directly using energy in production with predominantly domestic production chains, with imports and exports affected in same trends (Figure 7-a).

To further examine the differential impact of the taxes on the selected heavy industries, we decompose the petroleum processing, coking, and nuclear fuel processing industry into sub-industries. In carbon tax scenarios (A1), because the extent of the decrease in import is bigger than that of export, net exports of most energy intensive sectors tend to increase in the first 3–5 years then decrease in the next 10–15 years before becoming stable as a lower-than-baseline scenario. But the net exports of the electricity, chemical industry, and coke sectors decrease from the very beginning of the policy. Furthermore, the net exports of coke oven gas, other coke products, and other petroleum products sectors increase much more than those of other sectors and become stable at a higher level than in the baseline scenario. However, due to the different scale of sectoral effects, in scenario B, the chemical industry goes through a similar process as most of the other energy intensive industries. Net exports of the chemical industry increase by 0.54% in 2015 and then start decreasing in 2020, but do not decrease at the very beginning as in scenarios A1 and C1. Though the chemical sector’s exports are determined by its domestic prices, when taxes are first implemented, the price of chemical products increases quickly, dramatically shrinking domestic demand. Meanwhile, because of the lock-in effect of production technology, the producers cannot reduce production quickly in the short term. In contrast, a large part of the chemical sector’s production is used as intermediate inputs in other sectors, whose production levels will also decrease because of the rise in marginal costs. Demand for chemicals by other sectors therefore declines. Although total exports and imports both decrease, in the short-run, the decline in imports is larger than in exports, yielding a small increase in net export. In the long run, because demand for Chinese exports on the world market is an exponential function of relative prices, total exports of the chemical sector still decrease even after prices have adjusted.

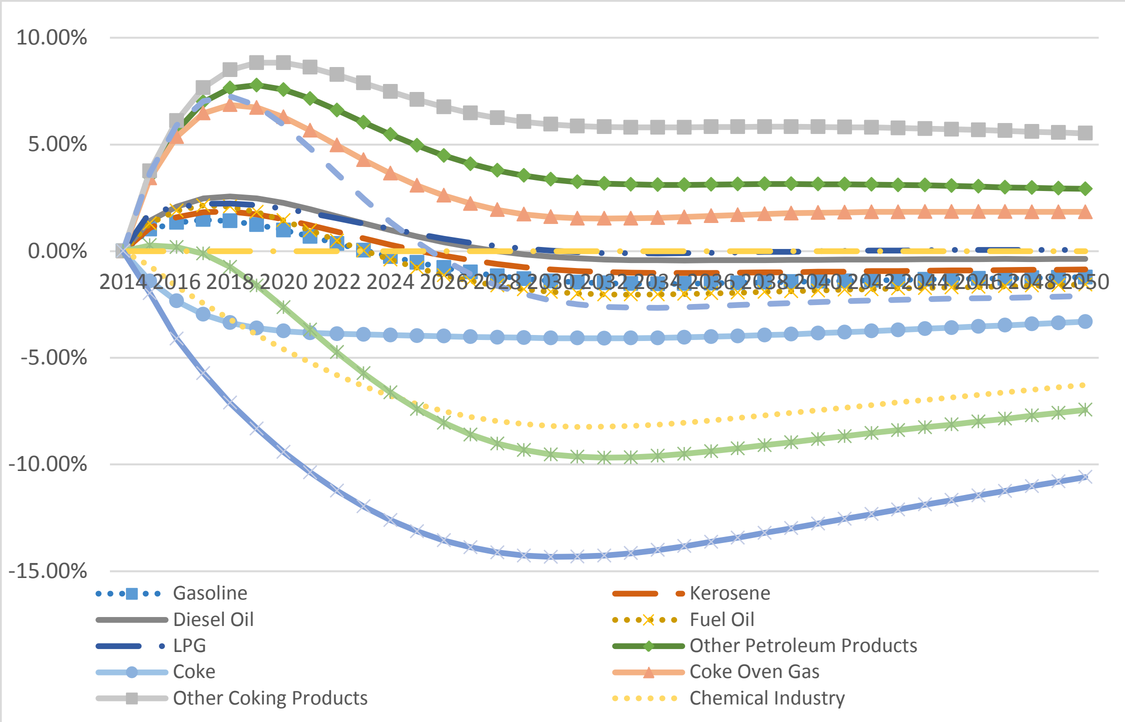
As mentioned above, electricity generation, the chemical industry, and the coke industries all demand large amounts of energy as inputs or intermediate inputs but are not direct consumers. The impacts of a carbon tax on these sectors’ net exports are more significant; meanwhile, in the carbon tax scenarios, net exports apparently rebound from 2030 to 2032—an outcome not seen in energy tax scenarios.



8-a Changes of net exports of energy intensive industries in scenario A1



8-b Changes of net exports of energy intensive industries in scenario B



8-c Changes of net exports of energy intensive industries in scenario C1

Figure 8 Changes of net exports of energy intensive industries

4.5 Impacts on the Competitiveness of Energy-Intensive Industries

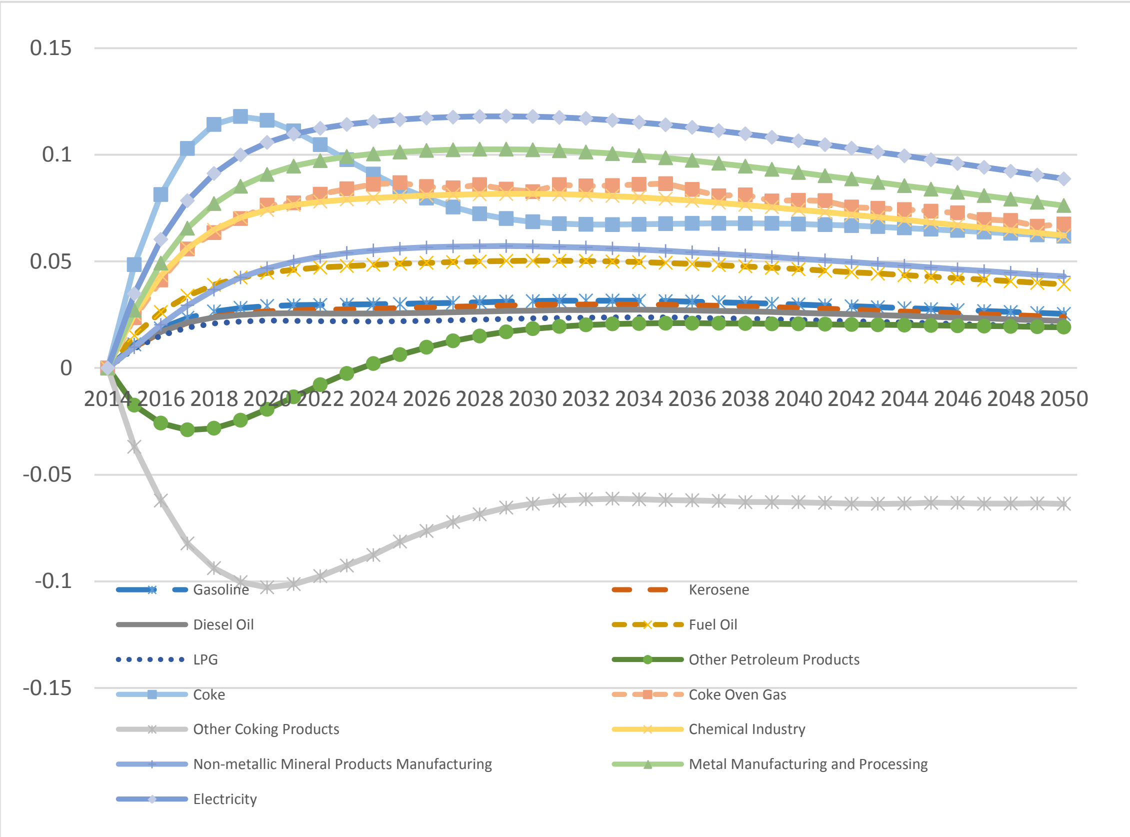
A major driver of China's rapid economic growth is thought to be the supporting role of heavy industrial goods in total exports. The cost of this "high export and high growth" strategy has been a subject of debate, with increasing number of researches pointing out that it is a transfer emission issue because these heavy industries export finished goods abroad while domestically emitting pollutants and greenhouse gases due to their relatively low production costs (Douglas and Nishioka 2012; Guo, Zhang et al. 2012; Ren, Yuan et al. 2014). Therefore, it is reasonable to worry that taxing these heavy industries would harm their competitiveness not only internationally but even domestically. It is therefore necessary to analyze the competitiveness of these industries considering the associated environmental costs, which can be accounted for by a carbon tax.

Definitions of "sectoral competitiveness" differ across researches, and most tax-related studies measure competitiveness by the share of domestic product exported to international markets (Baek, Jung et al. 2014; Meleo 2014; Wang and Wang 2014; Zhang 2014). However, in this study we are concerned more with the domestic market and want to reflect the impact of taxation on competition between domestic and imported goods. We therefore define the "domestic competitiveness" of a given sector as

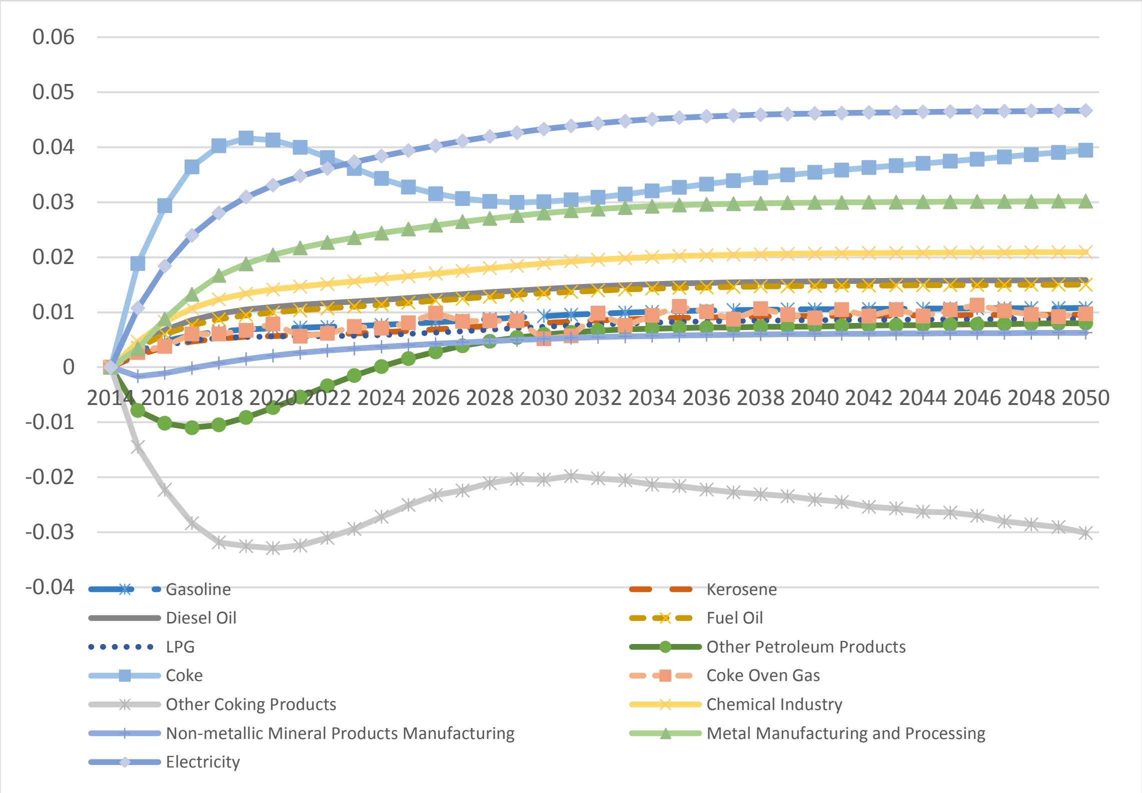
$$CMP_i = \frac{NE_i}{D_i} = \frac{E_i - M_i}{Y_i - E_i + M_i} \quad (9)$$

For a certain industry i, CMP_i is the domestic competitiveness, NE_i is net exports, D_i is the total domestic demand for industry i, E_i is net exports, M_i is imports, and Y_i is the total output of industry i.

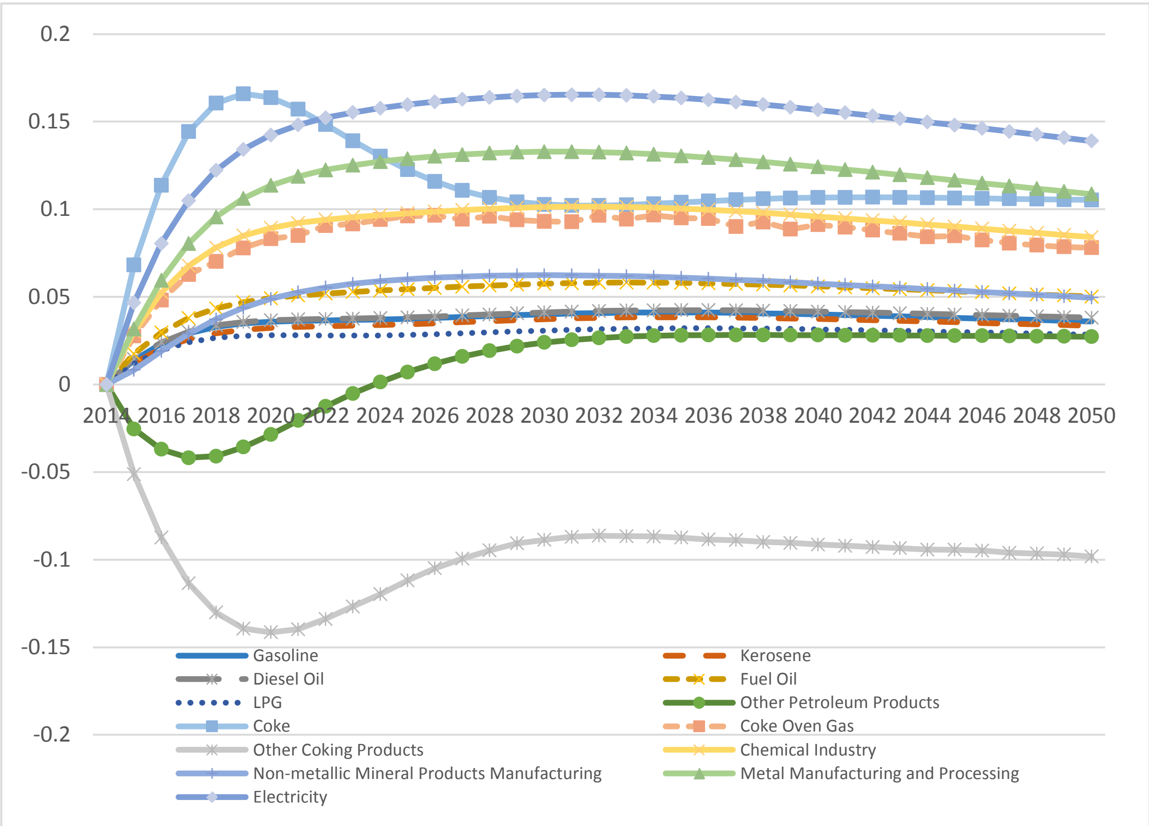
The proportion of imports in a sector indicates, to some extent, a sector's openness and dependency on foreign products, which together reflect the domestic competitiveness of a given sector. In contrast, the proportion of exports of a given sector out of total output reflects the relative importance of domestic and international markets. The higher the rate, the higher the sectoral export dependency. Therefore, when we examine the CMP in a given scenario, we could find that although the CMPs of other coking products and other petroleum products are lower than those in the reference scenario, all other heavy industries are more dependent on exports, which verifies the common perception of expansion of heavy industry exports as the main driving force of China's relatively high economic growth. Considering coking products and other petroleum products are a small part of the whole economy, it is reasonable to conclude that carbon and energy taxes both increase heavy industries' dependence on exports. The energy tax goes further and amplifies the effects of the carbon tax in scenarios C1–C3.



9-a Difference of CMP in A1 compare to baseline



9-b Difference of CMP in B compared to baseline



9-c Difference of CMP in C1 compared to baseline

Figure 9 Changes of CMP in A1, B and C1 compare to baseline

4.6 Comparison of costs and efficiency of energy tax and carbon tax

In this section, we try to discuss two questions: which tax reduces CO2 emissions more when they have the same total revenues (higher efficiency)? And, whose economic impact is larger when they reduce CO2 emissions by the same amount (lower cost)?

We take the 5% energy tax as a benchmark to analyze which policy is more effective in emission reduction while holding tax revenue constant. When the carbon tax is set at 11.87 RMB/ton of CO2, in 2020 the total revenue is the same as for a 5% energy tax, i.e., 92.66 billion RMB. The economic effects, however, differ. Compared with the effects of the carbon tax, the energy tax leads to a greater initial decrease in both energy and emission intensity followed by continued decline and higher velocity emission intensity, as shown in Figure 10.

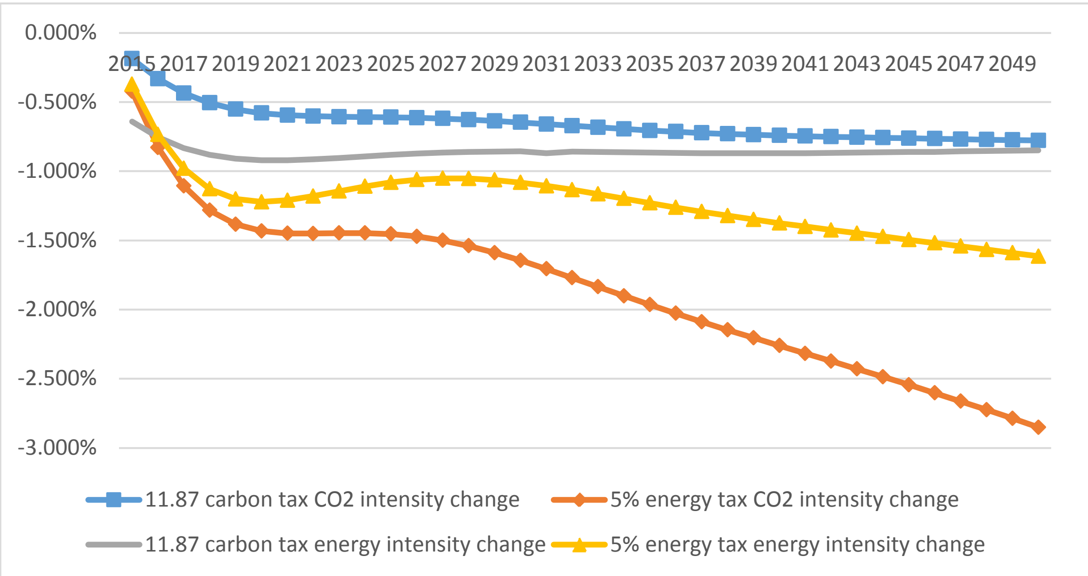


Figure 10 Emission intensity and energy intensity of 11.87 RMB carbon tax and 5%-of-price energy tax

Total emission reductions also differ. In the initial period, the carbon tax has significant effects of reducing CO2 by 408.17 million tons, while the energy tax induces reductions of 297.13 million tons of CO2, and this same relationship persists until 2021. Over time, the total reduction induced by the carbon tax abates, whereas that by the energy tax continues growing. By 2040, the total emission reduction from a 11.87 RMB carbon tax is 69.63 million tons of CO2, while that of 5% energy tax reaches 443.6 million tons of CO2, over six times as great.

Additionally, the impact on the broader economy also differs. In 2020, although the total revenue of the energy and carbon taxes are same and are both recycled to households, the GDP in the energy tax scenario drops 0.74% more than the baseline, while that of the carbon tax scenario drops only 0.37%, i.e., half as much. However, the gap is not as significant for real disposable income: the 11.87 RMB carbon tax reduces real disposable income by 0.325%, while the 5% energy tax results in a decrease of 0.378%. The difference in economic effects mainly comes from investments, including sectoral fixed investment and inventory, plus sectoral imports and exports. Because the carbon tax does not work directly on energy use but on all emissions, this mechanism offers more choices to the manufacturing industries regarding emission reduction measures, allowing the economy to recover and adjust through market mechanisms. In all carbon tax scenarios, GDP losses shrink annually. In 2030 and 2040, the loss compared to baseline is 0.230% and 0.215%, respectively. On the contrary, the energy tax is less flexible, resulting in GDP losses of 0.265% and 0.286% in 2030 and 2040, respectively.

For the sake of symmetry, we analyze the economic impacts of these two taxes while holding emission reductions constant. Still taking the effect of a 5%-of-price energy tax in 2020 as reference, we find that a carbon tax of 10.3 RMB/ton achieves the same level of emissions reduction. In 2020, both of these instruments reduce CO_2 by 369.64 million tons. The GDP loss with a 10.3 RMB carbon tax is 0.063% in 2020, gradually falling to 0.047% (2025), 0.040% (2030), 0.039% (2035), and 0.037% (2040), which are around 20% of GDP loss from the reference 5% energy tax (scenario B) in Table 1. Real disposable incomes also follow the same trend.

From the two comparison exercises above, we can conclude that an energy tax will have different effects than a carbon tax, namely they have different functions in terms of reducing energy use and carbon emissions. In a policy simulation, if we set emission reduction as the priority, the energy tax will act faster and more efficiently than the carbon tax, albeit with greater economic costs. In the long run, however, the energy tax will reduce energy intensity and CO_2 emission intensity significantly, while the carbon tax sees a rebound in both energy intensity and CO_2 emission intensity after an initial period of decline.

Some variant of the simulation scenarios laid out above is anticipated to be introduced in China in 2015. If for some reason, a tax policy was not implemented by that time, what would be the consequences of a delay? We first assume that the taxation policy starts one year later (2016). Under the 10 RMB scenario, in 2030, the fall in emission is 8.17% less than in scenario A3, which is projected as starting in 2015. If the taxation policy starts five years later (2020), then at the same tax rate of 10 RMB, emission decreases by 36.7% less than in scenario A3 in 2030. If the carbon tax starts from 2020 with a target of the same reduction amount in 2030 as in scenario A3, the 2020 tax rate should be 18.4 RMB, leading to a decline in GDP in 2030 i.e., 3.56% greater than that in scenario A3. In contrast, postponing the introduction of the tax will keep the economy growing in the same speed as the baseline, requiring a much higher tax to achieve the same emissions reduction as in scenario A3. Under this target, the tax rate rises to 23.57 RMB/ton of CO_2 emissions.

Similarly, when implementation of the energy tax is postponed to 2020, the tax rate should be set at 11.78% of the energy price to reach the same reduction amount of CO_2 emissions as in scenario B in 2030, and the GDP loss will be 5.71% more than that in scenario B. A tax rate of 17.21% of the energy price is required to achieve the same emission intensity in 2030 as that of scenario B, reducing GDP by 8.20%. Obviously these losses and costs are not acceptable.

5. Conclusions

In this study, we analyzed the function of a carbon tax, an energy tax, and their combined impacts on the whole economy and on industrial performance. Our principal conclusions are as follows.

In the long run, both an energy tax and a carbon tax help sectors to reduce energy use and corresponding CO2 emissions; in the short run, production costs will rise followed by a slight loss of GDP. In all scenarios, along with the increase in tax rates, a relatively modest decline in GDP will occur. In scenario A1, which shows the greatest policy response, GDP declines to 0.762%, the greatest loss across all scenarios. Although GDP losses are not the biggest, in the energy tax-only scenario (B), the impacts on total investment and total consumption are the largest. In 2020, the impact of scenario B on GDP is −0.272%, the second smallest after the rate observed in scenarios A3 and C3. However, its impacts on total investment and total residential consumption are −1.76% and −0.66%, respectively, the greatest of all scenarios. This means that compared with a carbon tax, the energy tax functions better with respect to sectoral investments for new projects or retrofits to existing projects. In other words, the energy tax is more effective at reducing production and consumption of energy-intensive products through the path of restricting investments in energy-intensive sectors.

Compared with the energy tax, the carbon tax has more obvious effects on reducing energy consumption and emissions in the short term. However, rebounds of energy use can be seen in carbon tax scenarios. Our simulations show that the energy tax works much more gradually, and the rebound effect is not significant. Energy intensity and CO2 emission intensity in all carbon tax scenarios (A1–A3, C1–C3) first show decreases followed by subsequent increases. In contrast, in the energy tax scenario (B), this trend is not observed. CO2 emissions intensity does not exhibit a U-shaped change in all scenarios. CO2 emission intensities in all scenarios monotonically decrease. Combined with other economic indices, this indicates that when energy intensity as well as total energy consumption rebound, CO2 emission intensity continues to decrease, indicating that the energy and carbon tax policies do work to promote “cleaner energy.”

A typical example is the power generation sector. China is still growing rapidly, and the increasing demand for power will induce more emissions. To meet the binding target of emission reduction and still ensure an adequate power supply, the power generation sector has to reduce the CO2 emissions through either technologies[5] such as clean energy technology, CO2 capture and storage technology, and efficiency improvement technology, or other ways like switching energy sources, which will all increase energy costs. The carbon tax would set an explicit price for the CO2 emissions, providing a clear and stable signal to justify investment to adopt cleaner power-generation technology.

[5] Although in this study we assume no significant changes in technology or energy structure in the whole time period of the simulation, the technology and energy structure still progresses following the natural course of evolution.

The choice of policy instrument should be based on the expected effect of the instrument. For example, the original purpose of both the energy and the carbon taxes was to reduce total energy consumption and CO2 emissions. In terms of reducing CO2 emission intensity, the carbon tax has a very clear effect from the point of implementation, and its effectiveness gradually increases. In contrast, the effect of the energy tax is initially relatively small but grows in the long run. With respect to the tax level, higher rates of both taxes bring larger economic shocks. Therefore, initial tax rates could start low to protect sectoral competitiveness and then increase over time to reduce energy use and CO2 emissions.

Energy and carbon taxes are not duplicative. Our analysis very clearly states that if an energy tax and carbon tax are levied simultaneously (scenarios C1–C3), CO2 emission intensity and energy intensity both decrease much more than if only one of the two taxes is implemented, while the impact on employment and outputs are relatively smaller, close to the effect of implementing the carbon tax or energy tax alone.

The energy-intensive sectors are still one of the major driving forces of China's economic growth[6]. In this study, we analyzed the impacts of these two taxes on energy intensive sectors. In general, the non-metallic products processing industry is the most influenced sector, including cement, glass and other products, followed by the metal products processing industry and petroleum products processing industry. These three industries are affected most severely in terms of both output and energy consumption. In contrast to received wisdom, the electricity production and delivery industry suffers the least. This might reflect the fact that compared with the other three sectors, the techniques and technologies of power generation are relatively unitary and the sector has greater technological flexibility because, for example the choice across fossil fuels and renewables represents a much broader fuel portfolio than that available to cement.

With respect to international trade, our analysis indicates that the energy tax carbon taxes influence both total imports and exports, but the effect on imports seems more significant. The sectors using energy as intermediate inputs or raw materials are shocked more than those only using energy as fuels. When we define sectoral competitiveness as the ratio of exports out of total demand, it means "the competitiveness of domestic products in domestic markets." In the baseline scenario, the CMP of most manufacturing industries are negative—except some light industries such as textiles and wood processing—which means that from the viewpoint of value, domestic industries are less competitive than the international average. However, with the energy and carbon tax policies almost all sectoral CMPs improve, except those of "other petroleum products" and "other coking products" industries. Additionally, similar to the effect on energy intensity and emission intensity reduction, the combined energy and carbon tax policies have greater effects on improving sectoral CMPs than implementing the energy tax only or carbon tax only, and also exert a greater

[6] The annual average contribution of secondary industry to GDP from 2004 to 2013 is 51.6% (data source: National Bureau of Statistics of China http://data.stats.gov.cn/workspace/index;jsessionid=BEF6DA9415820B5442F67FD1197C5E01?m=hgnd)

effect than the sum of energy and carbon tax scenarios. Therefore, if improving the competitiveness of domestic industries is one policy target, combined taxation is a good strategy.

For an energy tax or carbon tax policy, the later it starts, the higher the cost incurred to achieve the same amount of CO_2 reduction as a policy implemented earlier; in other words, China needs to launch the taxes sooner rather than later to achieve stated reduction targets at a lower cost. Postponing the carbon tax policy requires much higher tax rates and leads to greater economic losses.

In sum, this study conducted a primary analysis on the possible scenarios of introducing an energy tax and carbon tax and obtained some conclusions. However, many important issues still need to be addressed in further researches. For instance, revenue recycling is a key problem determining whether the tax policy is acceptable in practice. Different revenue investments directions, such as in certain sectors or technologies, public infrastructure or residents, decide the costs as well as the effects of emission reduction policies. Different revenue recycling scales, such as at the national or provincial level, decide the development balance of the whole economic system. In addition, maintaining competitiveness of sectors and products in international markets is also important. A complete analysis of international competitiveness requires integrating China’s economy into the global economic and trading systems as well as considering the sectoral characteristics of both domestic and international economies.

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